

## **Decline in radiation hardened microcircuit infrastructure**

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# Acronyms

| Acronym | Definition   |
|---------|--|
| ASIC    | Application Specific Integrated Circuit  |
| CDH     | Central DuPage Hospital Proton Facility, Chicago Illinois                                    |
| CNL     | Crocker Nuclear Lab  |
| COTS    | Commercial Off The Shelf   |
| ESA     | European Space Agency  |
| FPGA    | Field Programmable Gate Array  |
| GSFC    | Goddard Space Flight Center  |
| HUPTI   | Hampton University Proton Therapy Institute  |
| IBM     | International Business Machines  |
| IEEE    | Institute of Electrical and Electronics Engineers  |
| IUCF    | Indiana University Cyclotron Facility  |
| ITAR    | International Traffic in Arms Regulations  |
| LBNL    | Lawrence Berkeley National Laboratories  |
| LLUMC   | James M. Slater Proton Treatment and Research Center at Loma Linda University Medical Center |
| MGH     | Massachusetts General Hospital   |
| NASA    | National Aeronautics and Space Administration  |
| NEPP    | NASA Electronic Parts and Packaging  |
| NSREC   | Nuclear and Space Radiation Effects Conference   |
| NSRL    | NASA Space Radiation Laboratory  |
| ProCure | ProCure Center, Warrenville, Illinois  |
| SEE     | Single Event Effect  |
| SEU     | Single Event Upset   |
| TRIUMF  | Tri-University Meson Facility  |
| UCD     | University of California at Davis  |



# Abstract

- **Two areas of radiation hardened microcircuit infrastructure will be discussed:**
  - The availability and performance of radiation hardened microcircuits, and,
  - The access to radiation test facilities primarily for proton single event effects (SEE) testing.
- **Other areas not discussed, but are a concern include:**
  - The challenge for maintaining radiation effects tool access for assurance purposes, and,
  - The access to radiation test facilities primarily for heavy ion single event effects (SEE) testing.
- **Status and implications will be discussed for each area.**



# **U.S. RADIATION HARDENED MICROCIRCUITS**



# Radiation Hardened Microcircuits - Foundries

- Well known decline in number of U.S. manufacturers of radiation hardened microcircuits:
  - From 20+ in 1990 to a handful in 2015.
- Many of the existing suppliers utilize a “foundryless” model where they are either:
  - A design house using a 3<sup>rd</sup> party fabrication facility, or,
  - Upscreen parts while adding radiation mitigation approaches (shielding, supervisory control, etc...)
- Changes to ITAR (U.S. State Department to Commerce) should ease access to these products for non-U.S. entities not on restricted list.



# Foundries - Current Concern

- The cost of operating a dedicated state-of-the-art foundry is in the \$Billions.
  - Using a commercial fabrication facility (like IBM) as front end for silicon die with radiation hardened library development (intellectual property, IP) and a Military/Aerospace vendor as the back end (packaging, test) has been the working plan.
  - This is similar to European Space Agency (ESA) approach with ST Microelectronics, for example.
- Many future radiation hardened standard product and Application Specific Integrated Circuit (ASIC) plans were based on the use of the former IBM foundry that is now GlobalFoundries (non-U.S. owned).
  - While the use of non-U.S. foundries/products is common for NASA missions, the U.S. government, in general, is concerned over access to a U.S. foundry.
- U.S. Government is reviewing options at this time.
  - NASA may be affected indirectly for future standard product access, but does not develop many ASICs requiring advanced technology nodes.



# Radiation Hardened Microelectronics – More COTS?

- **The underlying challenge:**
  - Traditional radiation hardened electronics are multiple technology generations behind the commercial alternatives:
    - e.g., radiation hardened field programmable gate array (FPGA): 65nm feature size
    - Current state-of-the-art commercial FPGA: 20nm feature size. This is 3-4 generations more modern.
  - As technology has scaled, the power and volume versus performance metrics are improved – faster, smaller, more highly integrated, lower power.
- While NASA's been a user of commercial parts since the 1970's, these modern, very complex parts may require large amounts of additional mitigation for radiation sensitivities and evaluated for reliability challenges.
  - Modern system design mixes radiation hardened devices ("failsafe safing") with high-performing COTS devices.



# ALL ABOUT PROTONS



# Indiana University Cyclotron Facility (IUCF) Closure

- IUCF has been the most used higher energy proton test facility for most of the U.S. space industry (electronics).
  - It is primarily a medical facility that NASA and others have supported to develop a parallel capability for proton testing of electronics.
    - *~2000+ hours of use per year for electronics testing*
  - IUCF closed to the Space Community Usage on Oct 31, 2014.
  - High energy Proton Test (>200 MeV) is Critical to Space Community.
- Ad hoc U.S. government team formed to investigate options.
  - Existing proton SEE test facilities (North America).
  - Explore access to newer proton cancer therapy sites.
- Study began in 2014-Oct.



# Existing North American Proton Facilities

- **Tri-University Meson Facility (TRIUMF) – Vancouver, Canada**
  - Challenges with “border crossing,” limited “cycles” of availability
    - *TRIUMF is working w/ US State Department for easier access and hardware transfer*
- **Massachusetts General Hospital (MGH) Francis H. Burr Proton Therapy Center (additional access limited beyond current beam amounts),**
- **University of California at Davis (UCD) Crocker Nuclear Lab (CNL),**
  - Lower prime energy (63 MeV) does not meet all test requirements
- **Lawrence Berkeley National Laboratories (LBNL) – (50 MeV) has similar technical challenges as CNL, and,**
- **Loma Linda University Medical Center (LLUMC) and NASA Space Radiation Laboratory (NSRL) – have pulsed beam structures and other technical considerations.**



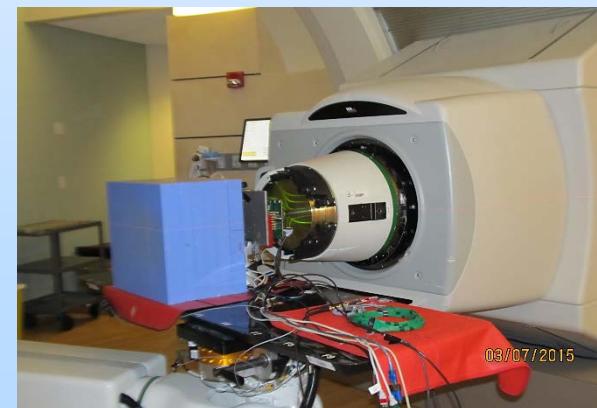
# Ad Hoc “Team” Plan/Status – Proton Therapy Sites

- ✓ Contact facilities (focus on cyclotrons)
- ✓ Site visit to determine interest
  - Technical
  - Access
  - Business case
- ❑ Beta/shakeout tests at interested sites to determine usability
  - ❑ Underway
- ❑ Work logistics of access
  - ❑ Underway
- Determine guidelines for usage of these sites
  - Goal is to discuss at IEEE Nuclear and Space Radiation Effects Conference in Boston, MA in July.
- Recommendations for modifications and longer term access.
  - TBD

**Assumption:** Facilities will have available 300-500 hours/year each (weekends).  
Multiple facilities required to replace IUCF in the near term.

# Challenges Identified with Using Proton Therapy Facilities

- **Technical**
  - Beam structure and delivery are mostly different than we are used to.  
*This is the largest technical concern.*
  - Independent dosimetry required for SEE testing – flux, fluence and uniformity.
  - Beam intensity control: translation between SEE test parameters and tumor delivery.
  - Beam stops required (therapy “stops” beam in patient).
  - Radiation dose limits may impact some higher fluence tests.
  - Remote-controlled movement of test article mounting stage may not exist at all sites – time hindrance.
- **Logistics**
  - Access
  - Scheduling
  - Cost



**Testing at Cadence Health Proton Center,  
Warrenville, IL USA**



# Background: Proton Beam Delivery

- There are two types of facilities being used for proton therapy:
  - Cyclotrons, and,
  - Synchrotrons.
- In addition, there are three types of beam delivery methods.
  - Scatter,
  - Wobble/uniform scan, and,
  - Pencil beam scan.
- *IUCF was a **cyclotron** and utilized a **scatter** beam delivery system.*
  - *Other options require thought and consideration for possible use.*



# Proton Facility Status

| Facility            |   | Location                     | Visit | Beam Attributes*         | User friendly** | Hourly Rate | Invest. required | Annual Hours             | Current Avail. | Short term Avail. | Long term Avail. | Beta Test |
|---------------------|---|------------------------------|-------|--------------------------|-----------------|-------------|------------------|--------------------------|----------------|-------------------|------------------|-----------|
| Future Facilities   | Cadence Health (CDH) Proton Facility - ProCure  | Warrenville, IL              | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | Maybe             | Maybe            | Mar 7     |
|                     | Hampton University Proton Therapy Institute (HUPI)  | Hampton, VA                  | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 350                      | No             | Maybe             | Maybe            | TBD       |
|                     | Provision Center for Proton Therapy   | Knoxville, TN                | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | No                | Maybe            | TBD       |
|                     | Seattle Cancer Care Alliance Proton Therapy - ProCure                                       | Seattle, WA                  | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | Maybe             | Maybe            | Yes       |
|                     | University of Florida Proton Therapy Institute  | Jacksonville, FL             | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | No                | Maybe            | TBD       |
|                     | University of Maryland Proton Treatment Center  | Baltimore, MD                | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | No                | Maybe            | TBD       |
|                     | Scripps Proton Therapy Center   | La Jolla, CA                 | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | Maybe             | Maybe            | May 1-2   |
|                     | OKC ProCure Proton Therapy Center   | OKC, OK                      | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | Maybe             | Maybe            | May-June  |
|                     | Mayo Foundation   | Rochester, MN<br>Phoenix, AZ | N     | TBD (synchrotron)        | TBD             | TBD         | TBD              | TBD                      | No             | No                | TBD              | TBD       |
| Existing Facilities | Tri-University Meson Facility (TRIUMF)  | Vancouver, CAN               | N     | Acceptable (cyclotron)   | Yes             | \$750       | No               | 4x/year                  | Yes            | Yes               | Yes              | N/A       |
|                     | Slater Proton Treatment and Research Center at Loma Linda University Medical Center (LLUMC) | Loma Linda, CA               | Y     | Acceptable (synchrotron) | Yes             | \$1,000     | No               | 1000                     | Yes            | Yes               | Yes              | N/A       |
|                     | Mass General Francis H. Burr Proton Therapy   | Boston, MA                   | N     | Acceptable (cyclotron)   | Yes             | \$1,000     | No               | < 800 hours, at capacity | Yes            | Yes               | Yes              | N/A       |
|                     | NASA Space Radiation Lab (NSRL)   | Brookhaven, NY               | Y     | Acceptable (synchrotron) | Yes             | \$4,700     | No               | > 1000 hours             | Yes            | Yes               | Yes              | N/A       |
|                     | Indiana University Cyclotron Facility   | Bloomington, IN              | N/A   | Reference                | Yes             | \$820       | N/A              | 2000 hours               | No             | No                | No               | N/A       |

\*Beam size, dosimetry, flux, fluence, uniformity; \*\*location, safety training, regulations, scheduling, payment, hazardous material handling, shipping, contracts, ITAR, etc...

European Space Research Institute (ESRIN) Trilateral Face-to-face (F2F) Working Group Meeting, Frascati, Italy, May 22, 2015.



# Proton Takeaway Chart

- **Rules of thumb**
  - All proton cancer therapy sites are usable for static tests, parts that are fairly proton-SEU tolerant, and destructive tests.
    - Cyclotron, synchrotron
    - Any of the beam delivery modes (scatter or scan)
  - Timing dependent tests (dynamic operations) especially on very proton sensitive devices require careful thought for using other than an IUCF-like beam (a cyclotron with a scatter mode).
    - Further work is needed to evaluate useful nature of scan beam delivery.
  - Guideline development will be a critical deliverable by this team.
    - Expect to have a version available at IEEE Nuclear and Space Radiation Effects Conference
      - Boston, MA. USA – July 13-17, 2015.



# Protons – The Future

- **Access/contracts/technical logistic “headaches” for cancer centers must be minimized to allow widest use for radiation effects research.**
  - We are NOT their prime customer.
  - Long-term access hinges on three items:
    - Minimum invasiveness of our community on cancer therapy sites (technical, logistics),
    - Business model (for cancer therapy sites), and,
    - Medical usage not expanding to use “spare time” – insurance and doctor access are current limits, but may be changing.



# QUESTIONS?